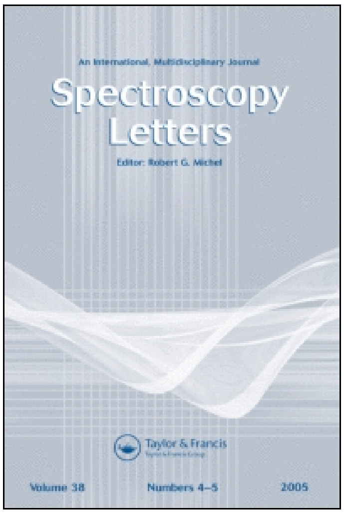

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Erosion of Thin Foils by Sputtering in Hollow Cathodes

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EROSION OF THIN FOILS BY SPUTTERING IN HOLLOW CATHODES.

Key words: hollow cathode discharge,

sputtering in hollow cathodes

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Abstract- A thin copper foil placed diagonally in a cylindrical copper hollow cathode undergoes fast erosion caused by cathode sputtering.Changes in the foil shape are related to current distribution along the hollow cathode axis.The experimental results aid in understanding the increase in spectral lines intensities emitted from conical bottom hollow cathode lamps.

Introduction.

It has been known for a long time that geometrical shapes of hollow cathodes undergo changes after prolonged operation. A cylindrical hollow cathode open at one end, has a tendency to change its inner surface to spherical shape [1]. The longitudinal cross section of a longer hollow cathodes resembles a string of spherical beads.

The basic cause of these geometrical changes is the shape and construction of the hollow cathode. In a cylindrical hollow cathode with the anode placed near to its open end the current distribution along the cathode axis is not uniform. This non-uniformity was observed previously [2] and will be described further. The presence of the open end of the cylindrical hollow cathode facilitates the diffusion of sputtered wall material to the outside of the hollow cathode.The non- uniformity of current distribution along the cathode axis creates maxima and minima of sputtering along the cathode wall. As the result of the diffusion of the sputtered material from the inside of the hollow cathode to the outside , the longitudinal distribution of the sputtered material inside the hollow cathode is different from the distribution of current along the cathode axis. Local maxima and minima of the redeposition of the sputtered material on the cathode wall (resulting from the back- diffusion from the plasma to the cathode wall) are shifted relative to the maxima and minima of sputtering current distribution. This shift of non-uniform sputtering and redeposition of sputtered material on the cathode wall is the direct cause of experimentally observed macroscopic changes in the geometrical shape of the hollow cathode.

The mathematical model describing this phenomenon of geometrical changes of the hollow cathode was presented by Hamisch and de la Rosa [3] who presented a set of a six coupled nonlinear differential equations describing the spatial density distributions of the main components of the hollow cathode plasma (Cu, Cu^{+} and Ne^{+}) . Using numerous simplifications involving temperature distributions and diffusion coefficients radial dependencies,the equations were solved producing qualitative agreement with experimental results.

One of difficulties connected with the experimental investigation of geometrical changes in a hollow cathode arises from the long time required to produce such changes and from the fact that the hollow cathode must then be examined by cutting apart along its axis. For a typical hollow cathode (3 to 5 cm long, 3 to 7 mm inner diameter) and using current of 300 mA, visible changes take place after about 200 hours of operation [3].In this article it is presented a simple method allowing observation of a geometrical changes in a hollow cathode using an operating time of about one hour.

Description of the apparatus.

The cross section of typical hollow cathode used in this experiment is shown in fig.1a. It was a cylindrical hollow cathode open at one end,having an inner diameter of 5 mm.The

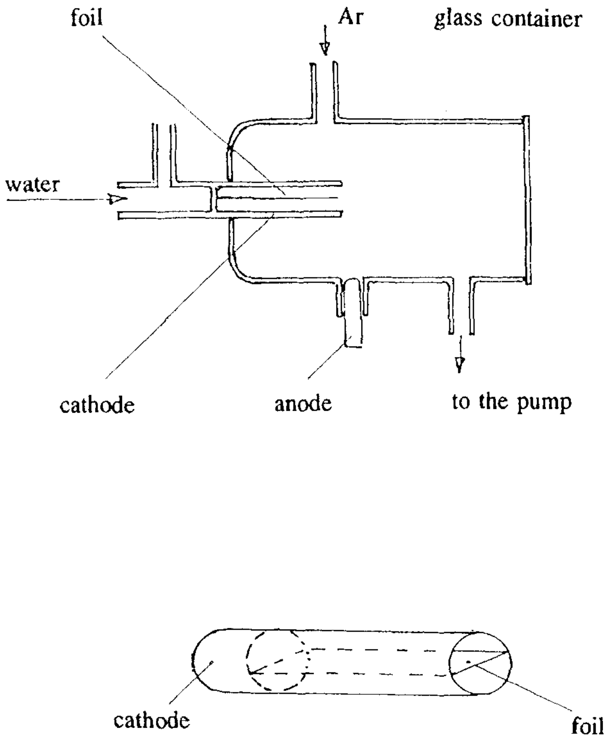

Fig.1 - A schematic diagram of the hollow cathode used in this experiment.The positioning of the foil in the cathode is shown in Fig.1b.

cathode was made of copper and argon at the pressure of 100 Pa (0.8 mmHg) was used as a buffer gas.The argon was slowly passed through the glass envelope surrounding the hollow cathode to ensure its purity. The cathode current was 200 mA and to conduct away the heat,the body of the hollow cathode was cooled with running water. A copper foil 0.2 mm thick was placed inside the hollow cathode as shown in fig.1b.The width of this foil was equal to the hollow cathode diameter to produce tight fit, and the foil reached to the bottom of the cylinder which was intentionally made flat.Thus the hollow cathode was divided into two similar cavities having a common wall. Essential for observation of geometrical changes due to sputtering is the fact that removal of 0.2 mm thick layer from the inserted foil produced easily visible holes. The removal of similar layer from the solid cathode wall was much more difficult to observe.

Results and discussion.

Figures 2a, 2b, 2c show holes obtained in copper foils placed in a 20mm- long cathode after various sputtering times. The areas of the holes are not proportional to the sputtering times. During the first 40 minutes,the first small hole was developed at a distance of 2 mm from the cathode bottom (fig.2a). After the next 15 minutes the area of this hole was greatly increased and at the same time a second hole appeared at 10 mm from the bottom (fig.2b). After an additional 15 minutes both holes merged as shown in fig.2c. The number of holes and places of their locations depended on the hollow cathode length. Figures 2d and 2e show results obtained for hollow cathodes 15mm- and 40mm- long. In the case of the 15mm- long hollow cathode only one hole appeared which rapidly increased in

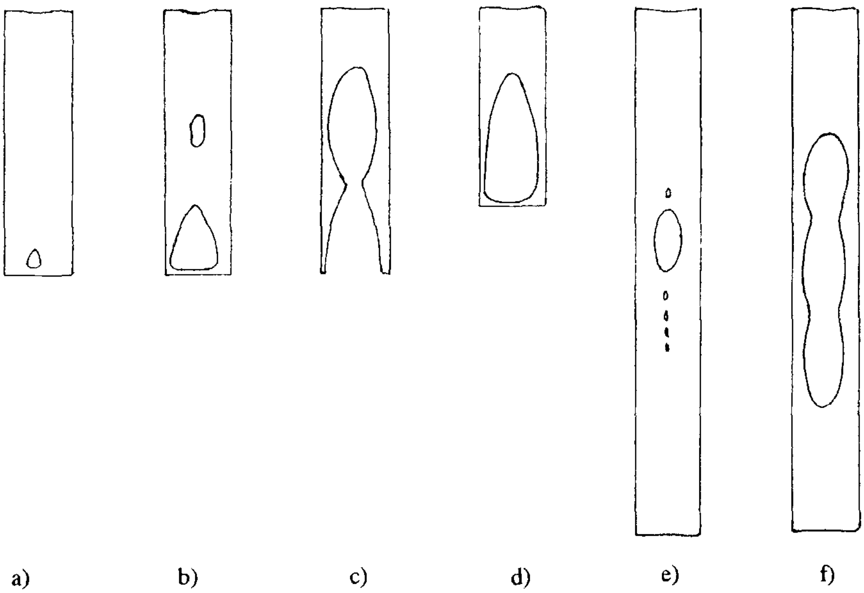

Fig.2 - The shapes of holes produced in foils placed in cathodes of various lengths :Fig.2a,b,c correspond to a 20mm-long cathode and 40,55,70 minutes of sputtering time; Fig.2d corresponds to a 15mm-long cathode and 50 minutes of sputtering; Fig.2e: 40mm-long cathode and 60 minutes of sputtering; Fig.2f:40mm-long cathode open at both ends and 60 minutes of sputtering.All cathodes except the cathode in Fig.2f are open at one end.

area. With the 40mm- long cathode a hole appeared 17 mm from the cathode open end, followed by a series of holes placed in various positions along the cathode axis (fig.2e). It was found that for hollow cathode having an inner diameter of 5mm first hole appeared invariably about 20 mm from open end. A decrease in cathode current led to an increase in the time needed to produce holes without affecting the shapes of the holes. With a 50 mA current a time of 5 hours was required to obtain results shown in fig.2. It might be possible to decrease this time by using thinner foils.

In addition to the experiments with cathode open at one end further experiments were also carried out with a cathode open at both ends and fitted with two anodes.The typical length of such a cathode was 40mm and the inner diameter was 5mm.The foil extended over the full of the cathode length.With this configur-ation sputtering started at the foil centre resulting in the appearance of a single hole and after 1 hour produced the effect shown in fig.2f.The symmetry of the pattern confirms our intuitive expectations.

A characteristic feature of the foil sputtering described in this article is the sequence of the sputtering process.For a cathode open at one end it starts at the bottom of the cathode and with cathode open at both ends it starts at the cathode centre.The parts of the foil situated near the open ends eroded more slowly and this erosion was rather weak within times of typical experimental runs. This observation is contrary to the assumptions made in Ref.[3],where the assumption of initial sputtering near the open ends of the cathode played an important role in the interpretation of the changes in the shape of the hollow cathode.

As mentioned above the changes in the geometrical shapes of hollow cathodes could be explained assuming a non-uniform distribution of current along the cathode axis. Such a distribution was measured by the authors of Ref. [2] for a one end open hollow cathode similar to that used in this experiment. To measure the electrical current distribution along the cathode axis,the cathode was built up of six annular sections,electrically insulated from one another.The current was found to have two maxima:a main maximum at the centre of the cathode and a subsidiary (smaller) at closed end. Although the discharge parameters of the hollow cathode described in Ref. [2] differed slightly from those employed in this experiment and the other cathode was also cooled with liquid air,the two cathodes showed a striking agreement between positions of current maxima (at the centre and at the closed end) and the positions of maximal sputtering shown in fig.2a,b,c is . It appeared that the degree of sputtering of a foil placed in the hollow cathode follows the current distribution along the cathode axis.

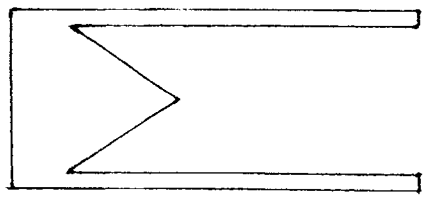

Fig.3 - Longitudinal section of a hollow cathode with a conical bottom described in Ref.[4].

The location of sites in a hollow cathode at which there is increased sputtering, can be of assistance in understanding the results obtained with a hollow cathode spectral lamp of modified construction,described in Ref. [4]. The longitudinal cross section of the hollow cathode used in such a lamp is shown in fig.3. The authors compared the intensities of Al and Cu spectral lines emitted from a flat- bottom hollow cathode lamp to the intensities emitted the from conical- bottom lamp.The intensities were measured keeping the main discharge parameters in both lamps the same,and it was found that the spectral lines intensities emitted from the conical- bottom lamp were several times stronger than corresponding lines intensities emitted from a flat bottom lamp.The intensities of buffer gas lines were similar for both lamps .The simplest explanation of the intensity enhancement can be obtained assuming stronger sputtering in the conical- bottom than in a flat- bottom hollow cathode. This explanation which was suggested in Ref. [4] is supported by the results which are obtained with foils placed in the hollow cathode. In particular, considering the shape and distribution of the holes in the foils shown in Fig.2, we conclude that the sputtering action is unexpectedly strong at the bottom of the hollow cathode. The fact that the intensities of the spectral lines were found to be independent of the sharpness of the cone-tip [4], correlates well with the oval shapes of the sputtered holes shown in Fig.2.

The above method by which the macroscopic effects of sputtering in a hollow cathode may be observed, is particularly useful for the determination of the time evolution of this process. The system of differential equations describing the phenomenon of geometrical shape changes in a hollow cathode as presented in Ref. [3] is rather difficult to solve because of nonlinearities and I believe that these experiments can be helpful in detail studying of the sputtering process in a hollow cathode.

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